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DEVELOPMENT OF A 7-INCH AIR GUN FOR USE IN INTERIOR BALLISTICS SIMULATION

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A 7-in. diameter, 98-ft-long air gun has been installed at the Harry Diamond Laboratories (HDL) for use in fuze testing. The air gun is bidirectionally interfaced to a timeshare computer that acts as the test controller and promptly records test data. Streak photographs taken of the simulated ballistic environment are reduced by a computer-controlled microdensitometer. The resulting digital data are further computer analyzed to provide velocity versus time and acceleration versus time profiles of the test environment.

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This report details the purchase, inspection, acceptance, and construction of the 7-in. air gun. Instrumentation and data reduction procedures are described. To date, 34 air-gun shots have been made. Projectile velocities up to 530 ft/sec have been attained. Average impact test accelerations of 15 kg from 1.2 to 1.5 msec in duration have been achieved.

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1. INTRODUCTION

Gas guns are laboratory devices used to accelerate projectiles to high velocities. The HDL gas guns are used in conjunction with other equipment to simulate the inertial forces experienced by a fuze or fuze component when artillery fired. In this technique, the gas gun accelerates the fuze to a desired velocity; then the item impacts into a preselected target. At impact and during target crush, the fuze experiences a deceleration similar to that of the actual ballistic environment.

A 7-in. diameter, 98-ft-long gas gun was recently installed at HDL. Air at atmospheric pressure propels the piston-like test projectile through the evacuated gun. Future plans allow an increase in the overall gun length from 98 to 314 ft.

The 7-in. air gun is computer controlled and bidirectionally interfaced. Instrumentation data are promptly recorded in computer memory and the computer is programmed to calculate, amongst other things, projectile impact velocity and average impact test deceleration. A formatted output of test parameters and calculation results is available within 10 min of the test. The projectile's position-time history during impact is recorded by utilizing streak photography. Information amassed on the photograph is digitized by using a computer-controlled microdensitometer. Velocity versus time and deceleration versus time curves are generated by computer analysis of the data. These curves and data are available within 4 hr after the test.

This report presents the development, procurement, inspection, and acceptance details of the 7-in. air gun, as well as a brief description of HDL's use of the air gun in ballistic simulation. Also, the instrumentation used and data reduction procedures are discussed. Results of initial shots, as well as future plans and recommendations are presented.

2. DESIGN APPLICATION

2.1 Air-Gun Operation in Ballistic Simulation

The air gun accelerates a projectile to some desired velocity over a distance that is long compared with the stopping distance. Air at atmospheric pressure and temperature propels the bird (projectile) through the evacuated gun (fig. 1). During pumpdown, the breech of the

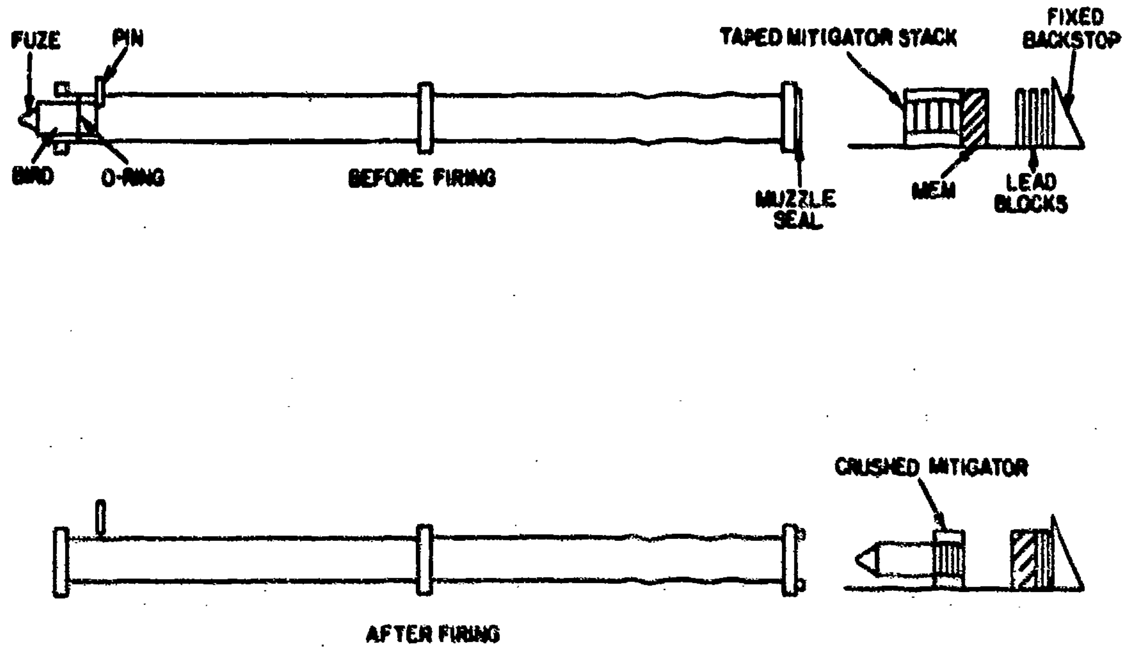

Figure 1. Air gun operational phases.

gun is sealed by the slightly undersized bird (typically 0.005 in. less than bore diameter) seated within an O-ring that is retained within the gun. A pin restrains bird movement during this procedure. The muzzle is vacuum sealed by a diaphragm of mylar sheet, 0.0015 in. thick, secured between a muzzle seal and an O-ring on the face of the gun. Mylar is used because of its capabilities to withstand high tensile stresses set up by the large pressure gradient, yet it readily shears when punctured by the bird.

When the desired vacuum is achieved, the pin is retracted and the bird released. The peak acceleration sustained by the bird in the air gun is approximately 100 g.

2.2 Ballistics Simulation

The air gun propels the bird to the velocity required for a particular ballistic simulation. The bird, in most tests, acts only as a carrier for the fuze or fuze component being investigated. After exiting the gun, the bird impacts a migitator-momentum exchange mass (MEM) configuration (fig. 1). It is in this impact event that the bird sustains the controlled deceleration. Since the test item is mounted so that it faces in opposite direction to the approach, this deceleration corresponds to the setback forces that would be perceived by the fuze when weapon-fired. The bird is effectively brought to a standstill within a short distance with its energy and momentum absorbed by crush of the mitigator and motion of the MEM. The resultant deceleration is a function of the type of mitigator, MEM mass, and bird mass.[1]

3. DEVELOPMENT DETAILS OF 7-IN. AIR GUN

3.1 Basic Objective

The 7-in. air gun is needed to test larger mass and larger diameter fuzes than can be accommodated in the HDL 4-in. air gun. Space limitations at the HDL Washington site however, restrict usable gun length to 100-ft maximum. Thus, the 7-in. gun will be lengthened to 314 ft when the gun is relocated to the new HDL site (Adelphi, MD) in 1976. Consequently, essential components were procured for use with the 98-ft gun, as well as for subsequent use with the 314-ft gun (table I).

TABLE I. SECTIONAL BREAKDOWN OF 7-IN. AIR GUN

Quantity	Section	Total length (ft)
12	24-ft tube	288
2	10-ft tube	20
1	Breech	2-1/2
1	Expansion Chamber	3-1/2
	Total length (ft) --	314

[1] *H. D. Curchack, An Artillery Simulator for Fuze Evaluation, Harry Diamond Laboratories Report HDL-TR-1330 (Nov 1966).*

3.2 Fabrication

The gun tubes are made of cold-drawn steel honed to a 7.033 ± 0.002-in.-bore diameter. The bore is polished to a 32- in. finish, whereas the external tube surface is in the "as drawn" state. Tube ends are flanged, have a rabbet fit, and an O-ring groove. The bore diameter of the female joint (the end nearest the muzzle) is always larger than that of its mating section; thus obstruction to the bird is minimized as it passes through the joint. The 7-in. gun is supported by a stand at each flange. The 24-ft sections are also flanged at the center, which makes a maximum distance of 12 ft between stands. Flanges are clamped to adjustable supports that permit both vertical and horizontal axial tube alignment.

3.3 Inspection Procedure

The tube sections were inspected at the manufacturer's plant during gun fabrication. In addition to usual dimensional checks, tube straightness and bore-diameter variations were determined with an ATI laser tooling/alignment system (fig. 2) and a spiral-wave gauge (fig. 3) designed by the manufacturer.

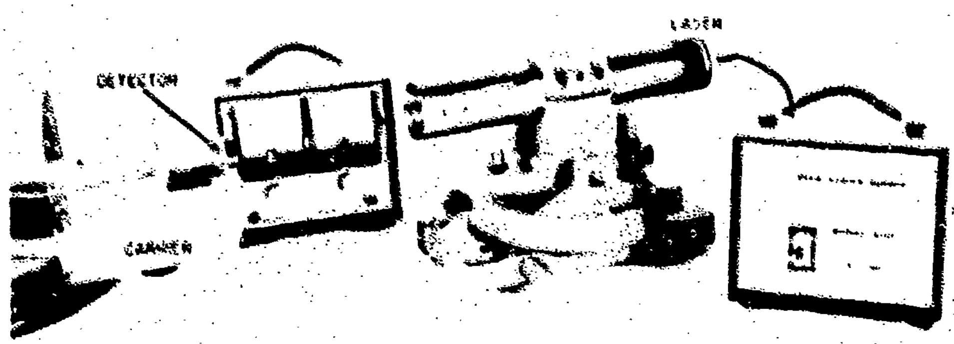

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Figure 2. ATI laser tooling/alignment system.

The spiral-wave gauge uses a dial indicator to measure the deviation (in 0.0001 in.) of the tube wall from an imaginary line drawn between the points of contact of the wheels and the tube. Designed primarily to determine the existence of spiral waves that result from

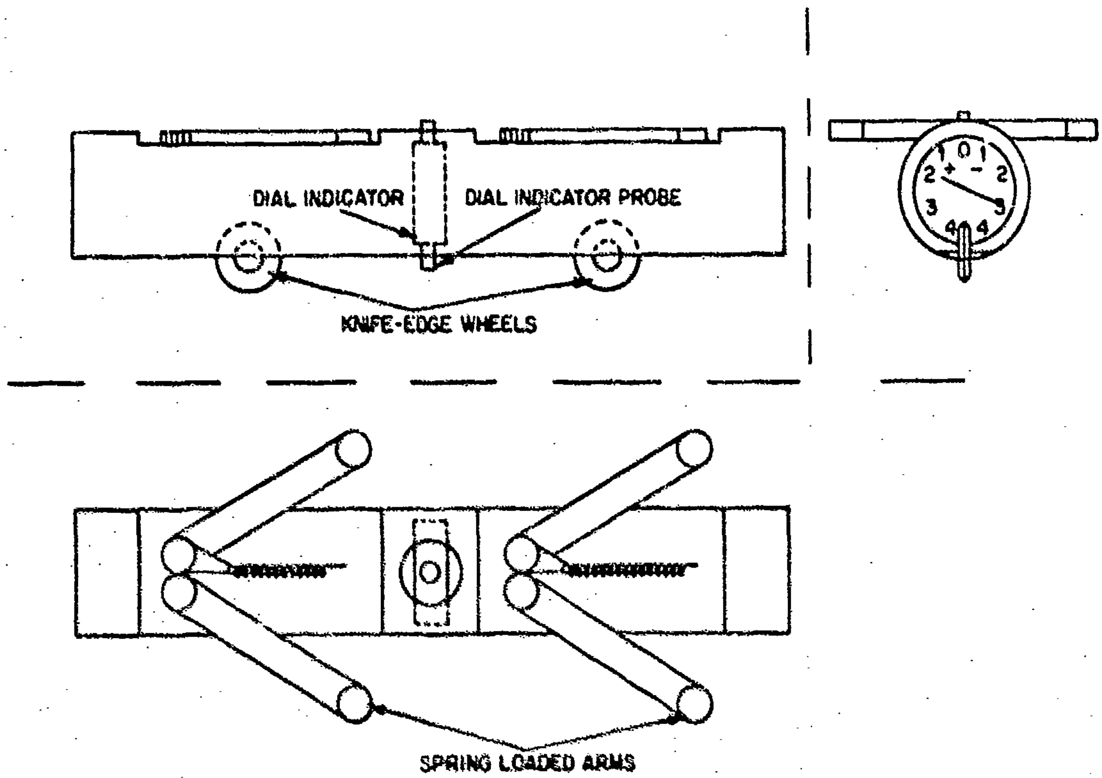

Figure 3. Spiral wave gauge.

the drawing process, spiral-wave-gauge data was computer reduced to determine tube straightness and bore-diameter variations (app A). The gauge is centered on a platform that is supported by two knife-edge wheels (fig. 3).

The inspection procedure consisted of taking readings at intervals equal to the distance between the dial indicator probe and the knife-edge wheels (see fig. 3) while the device was drawn along the inside of the tubes. A battery-powered light, built into the device, permitted telescopic reading of the dial indicator. After a complete set of readings were taken, the tube was rotated 90 deg about its longitudinal axis and the procedure repeated. A tape measure fixed to the spiral-wave gauge was used to reference the position of the dial indicator to one end of the tube.

The laser tooling/alignment system includes a helium-neon laser that projects a constant diameter light beam. The collimated light falls upon a detector target consisting of a photoelectric cell partitioned into four quadrants. Each quadrant emits a current proportional to the amount of light that falls upon it. The detector is electrically attached to a readout unit that displays on two meters (in 0.001 in.) the horizontal and vertical deviations of the laser beam from the target center.

Using this system, the inspection procedure has the detector target centered in a cylindrical carrier that is designed to follow the tube contour. A steel-tape measure is affixed to this carrier so that the location of the detector is referenced to one end of the tube. The laser is aligned so that its beam passes through the center of each tube end. The carrier is then drawn through the tube starting at one end, with the vertical deviation recorded at 6-in. intervals. This process was repeated with the tube rotated at 90-deg intervals until four sets of readings had been taken. These data were processed to yield bore-diameter variation and deviations from an optical axis passing through centers of both tube ends (app B).

Problems arose with the use of this laser due to convection currents and general room vibrations. Both situations created an erratic shift in reading superimposed on the true reading. The problem was minimized with a makeshift assembly that enclosed the laser and tube end to reduce the effect of convection currents. Vibrations from equipment and personnel were minimized by working in an isolated area of the plant.

The final acceptance procedure also requires that an inspection gauge (fig. 4) be drawn, without binding, through randomly mated tubes.

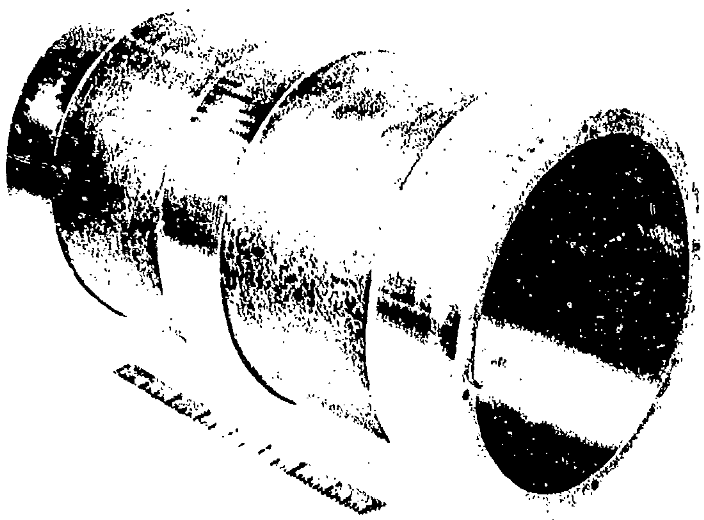

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Figure 4. Inspection gauge.

The gauge is 14 in. long; at the 2-in.-wide bands, the diameter is 0.005 in. less than the nominal bore diameter. Unobstructed gauge passage through the tube and juncture insures appropriate alignment of the mated tubes for test projectiles customarily 5 to 8 in. long. Pressure tests of the coupled tubes and the expansion chamber were also performed to insure proper vacuum seals. These tests involved sealing the open ends of the mated tubes or expansion chamber, then applying 5 psi air. A liquid soap solution was applied to joints and seals to detect possible leaks. Two minor leaks were discovered in the expansion chamber that resulted from a design oversight carried over into the actual fabrication.

3.4 Assembly

Three 24-ft sections, two 10-ft sections, the breech section, and expansion chamber were assembled to construct a 98-ft air gun (fig. 5). The additional tube sections were purchased for use in early 1976 at the new HDL site. Each tube intended to be stored was coated internally with Shell V.P.I. 260 Volatile Corrosion Inhibitor before being sealed with cover plates. The tubes used in assembling the 98-ft gun were thoroughly degreased and wiped before installation to eliminate oils and metal slivers remaining from the honing process.

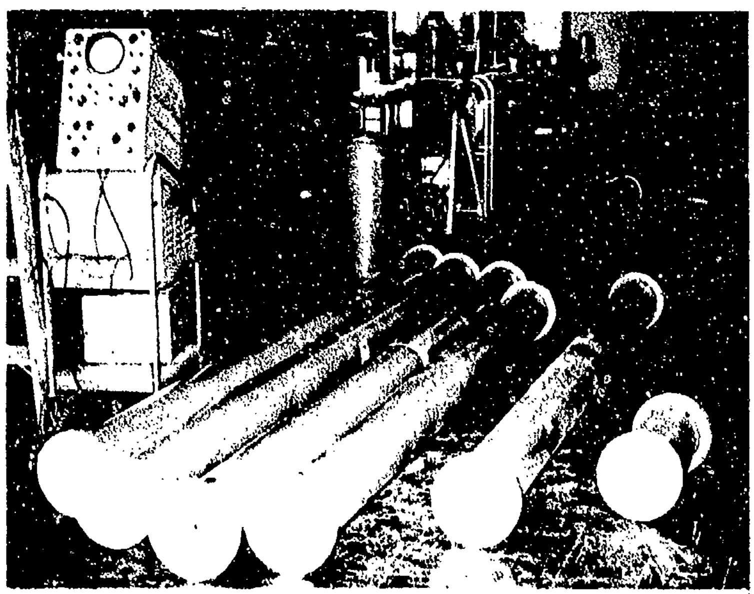

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Figure 5. Tube sections used in 98-ft-gun assembly

3.4.1 Gun Tubes

The selection of specific 24-ft tubes for the 98-ft gun and their arrangement was resolved from laser data obtained during the inplant tube inspections. The "best" tubes were chosen in setting up the gun--the "best" being determined as having minimum curvature at tube ends. This was done so that (1) evaluation of the gun would be accomplished under optimum conditions, (2) adjacent tubes could be mated easily, and (3) the bird would have smoothest transition across the joints. The order of alignment was also resolved by employing this same tube straightness standard. To maximize efficiency at the muzzle where the driving force is minimum and to prevent whip of the projectile at gun exit, the "best" tube was coupled to the expansion chamber. To reduce gas blowby at the breech where the driving force is highest, the remaining tubes were aligned "best" to "worst" commencing at the breech.

The tubes were installed and aligned, using both the laser system and the 14-in. inspection gauge. The laser beam established a horizontal optical axis through the center points of each end of the expansion chamber and the gun was then assembled along this beam (fig. 6). As each tube was added, the detector target was drawn through

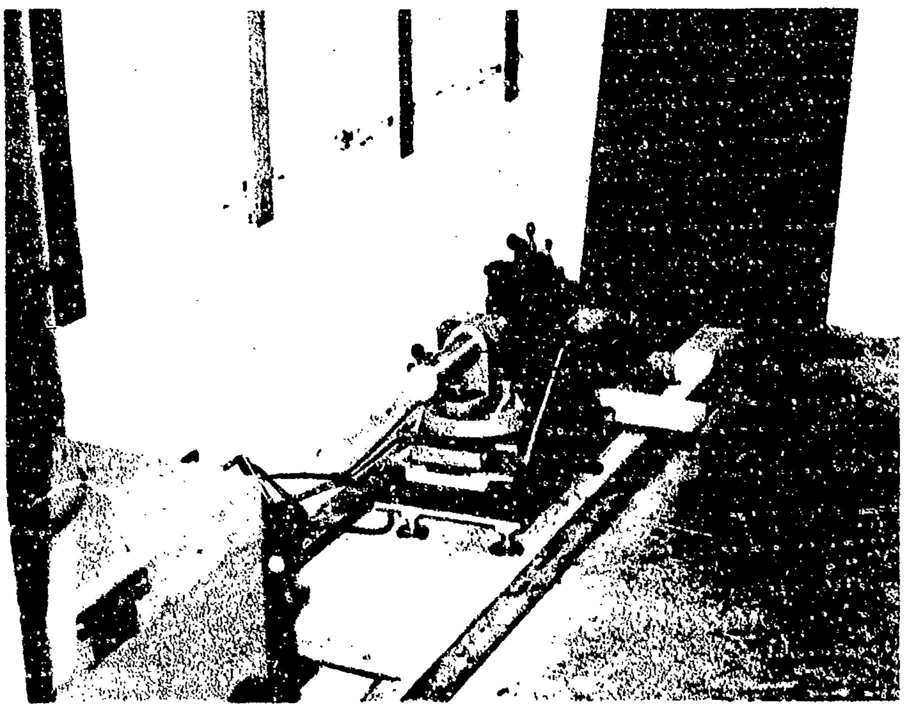

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Figure 6. Laser setup used in gun construction.

the tubes, positioned over a stand, and the orthogonal stand adjustments corrected to bring the tube-centered detector into alignment with the beam as indicated by zero deflection on the readout units. The final alignment criterion remained the smooth passage of the inspection gauge past the juncture. If the gauge became obstructed, the adjoining stand closest to the breech and the stand beneath the joint in question were adjusted until free passage ensued. If this failed, the tube being coupled was rotated and the procedure repeated. In the case where the stands had to be adjusted for passage of the inspection gauge, the maximum variation from the axial alignment was found to be 0.015 in.

3.4.2 Catch-Box Room

The ballistic-simulation process occurs within a 6- by 11- by 8-ft reinforced concrete room called the catch-box room. The expansion chamber is anchored to two parallel I-beams on the catch-box room floor and to the front inside wall of the room. A mitigator-MEM target stand and a wall backup plate were aligned with the direction of exit of the bird; an alignment method was used, which centers the laser inside the expansion chamber over the final 8 in. of gun tube (fig. 7). After

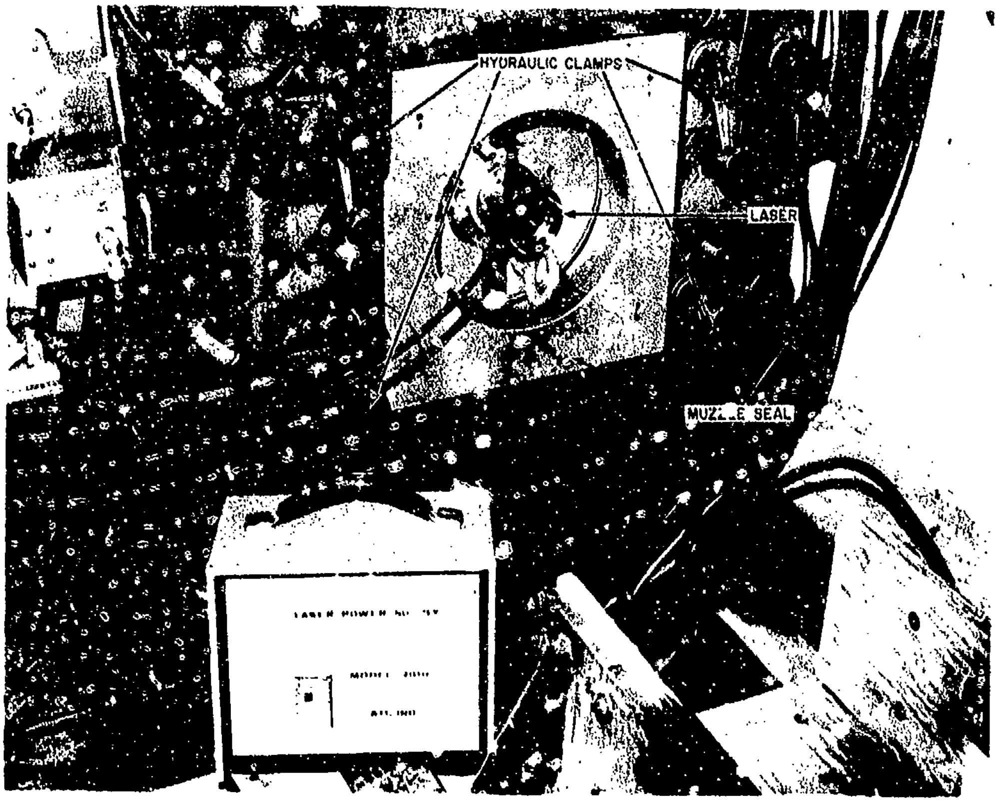

Figure 7. Alignment tool determining direction of bird exit.

alignment, the backup plate was bolted to the back wall of the room and the target stand was fixed to the parallel I-beams on the floor. Supporting rails for the streak camera were installed so that the photo lens of the camera is 30 in. above the mitigator-MEM target. All wiring required for this camera and for instrumentation in the catch-box room extends through a trough beneath the expansion chamber to an exterior room.

Preliminary setup shots demonstrated the need for a MEM "capture" box to prevent damage from the ricocheting MEM. A container of welded 0.5-in.-steel plates was constructed specifically to catch the MEM (fig. 8).

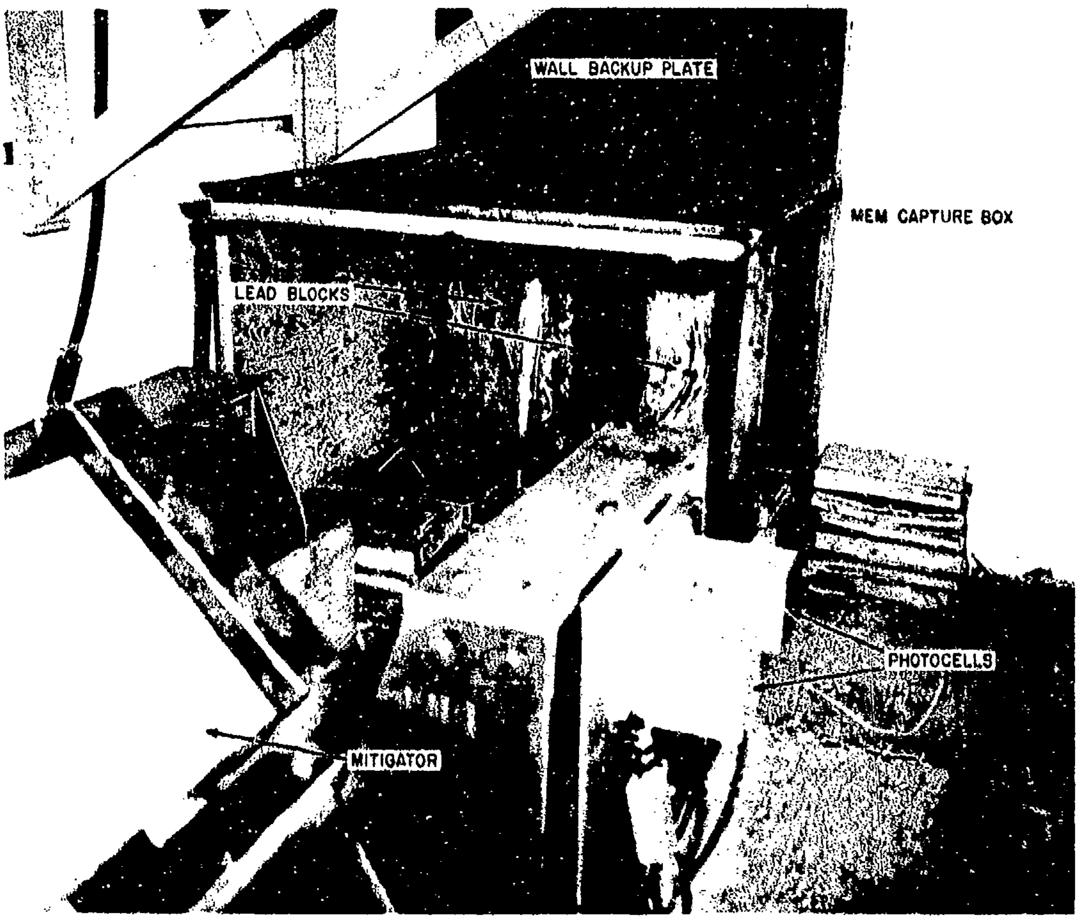

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Figure 8. MEM capture box.

3.4.3 Diaphragm Assembly

The diaphragm assembly for the 7-in. air gun uses four hydraulic clamps symmetrically positioned to provide uniform pressure on the cover plate (fig. 9). The cover in turn clamps a 0.0015-in. mylar sheet against an O-ring embedded in the face of the expansion chamber. The setup provides vacuum-tight assembly and clamping strength that preclude the mylar from slipping in spite of the large force on the diaphragm. In addition, the design permits easy, rapid change with minimum chance of damage to the mylar diaphragm. Each Hydra-Dyne Swing Clamp furnishes 636-lb force per 1000 psi of supply-oil pressure. A Hydra-Dyne Power Booster is employed to convert 90-psi air line pressure to the required 2500 psi of hydraulic pressure.

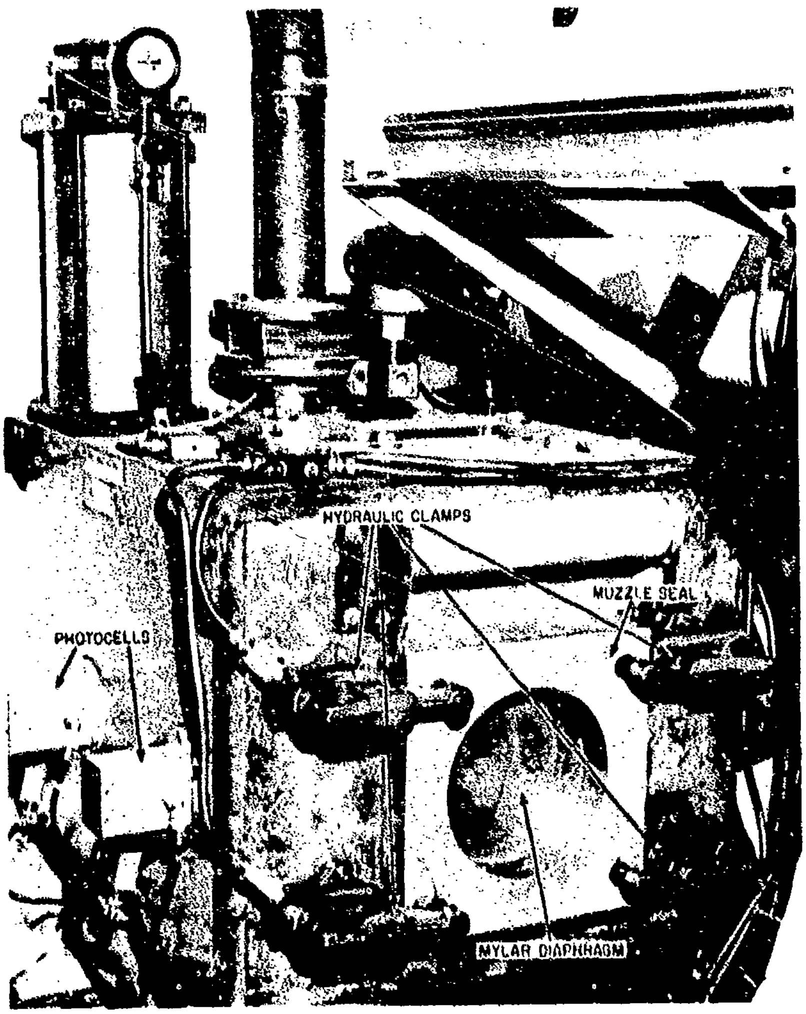

Figure 9. Diaphragm assembly and expansion chamber.

3.4.4 Breech Section and Release Assembly

The breech section includes a 2.5-ft section of honed tubing that contains three O-ring grooves and a housing for the pin-release assembly (fig. 10). The O-ring grooves were inadvertently machined to an o.d. larger than that specified. A satisfactory vacuum seal is achieved, however, by stretching the O-ring which is presently a Parker 2-262. The pin release assembly has a 1-in. diameter piston activated by 90 psi air that is controlled by a 110-V single-solenoid valve. The 1-in. piston is sealed to the housing by two O-rings.

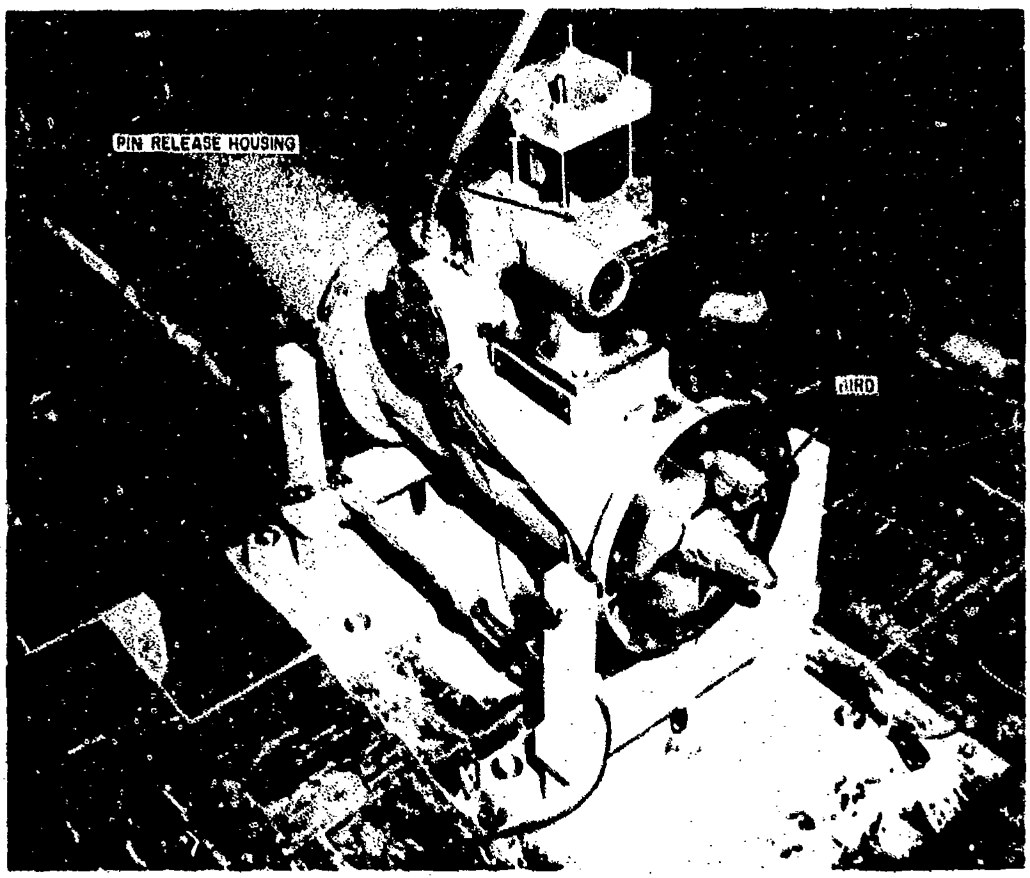

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Figure 10. Breech section and release assembly.

3.4.5 Vacuum System

After coupling the first tube section to the expansion chamber, the vacuum pump, piping, and essential valves were installed. The vacuum pump was mounted on a welded steel table located outside the catch-box room over the first tube section (fig. 11). Rubber pads isolated the table from the floor and reduced vibrational clatter. Later design changes will include fastening the table to the floor and extending the pump exhaust, and thus its noise, outside the building.

When the 7-in. air gun was completely assembled, cover plates were placed at the breech and muzzle sections and a vacuum was pulled. A Mass Spectrometer Leak Detector (General Electric, type H-60) was placed in parallel with the vacuum system. Release of helium as a probe

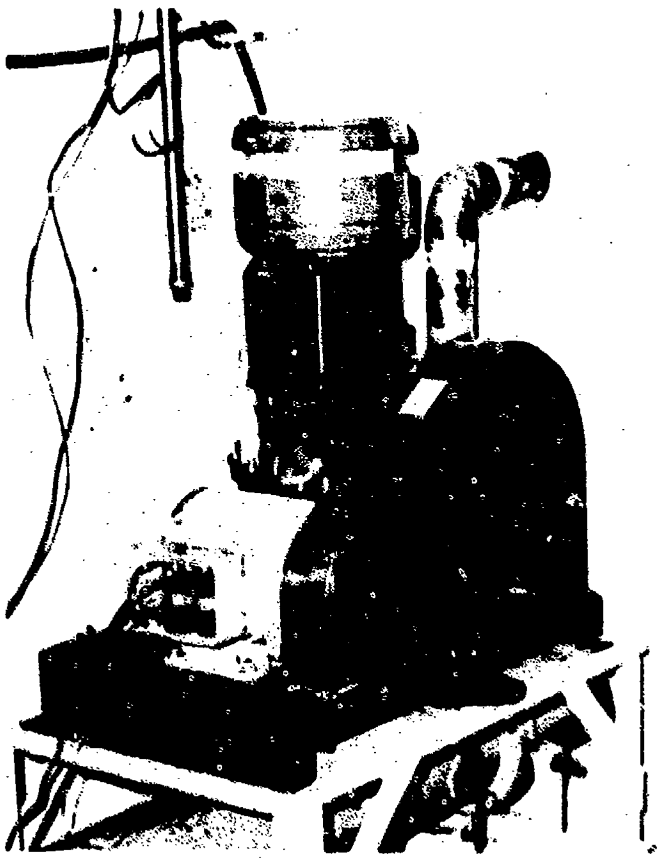

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Figure 11. Vacuum pump and table.

gas around the flanges demonstrated that the tube flange connections were vacuum tight. However, numerous leaks were discovered and corrected on peripheral equipment tied into the expansion chamber. One small leak found in a valve could not be corrected without extensive revamping of the vacuum piping. This leak does not unduly impair preliminary gun test and will thus be fixed when the vacuum pump is removed to tie the table to the floor.

4. INSTRUMENTATION

4.1 Photocells and Timer/Counters

A pair of Texas Instrument photocells (type L66) is used in conjunction with light sources to measure projectile velocity. These photocells, situated 1 ft apart, are built into the expansion chamber (fig. 9). As the bird interrupts the photocell light beams, 11-V output pulses are generated that start and then stop a Hewlett Packard 50-MHz timer/counter (model 5326B). Consequently, the timer/counter indicates bird transit time precise to 1 µsec; the reciprocal of this value yields the average velocity, which is also impact velocity. The stop signal, in addition to stopping the counter, pulses a delay line that triggers the streak camera flash unit prior to impact.

A method is being developed to compute an average acceleration over the impact event directly from time data rather than from measurement of mitigator crush as done previously (app C). In addition to the projectile impact velocity measurement, this new method requires the measurement of the NEM velocity after impact. For this reason, a second pair of photocells (fig. 8) is placed to detect NEM passage across a 6-in. interval. A second Hewlett Packard 50-MHz timer/counter (model 5326B) is used to measure the time interval between photocell start and stop pulses. A third counter is required to measure the time between the stop pulse triggered by the bird in the expansion chamber and the start pulse triggered by the NEM. A Beckman counting unit (model 6380) is being used for this purpose.

A Hewlett Packard 50-MHz timer/counter (model 5326A) records the time interval for one complete revolution of the streak camera drum to 1 µsec. The measurement is made at the time that the impact event is photographed. Two 3-V pulses are generated by the streak camera control unit to start and then stop the timer.

4.2 Computer Control

The 7-in. air gun is computer operated through a Hewlett Packard 2570A coupler/controller (fig. 12). This device functions as a bidirectional interface between the gun and a timeshare computer. The underlying principle of operation is the capability to transform digitized information into ASCII computer code and vice-versa. Equipment power on, safety constraints and gun-firing command originate from a 16-bit relay register card interfaced into the system (fig. 13). All instructions are programmed in basic from the GE Mark III Timeshare Service.

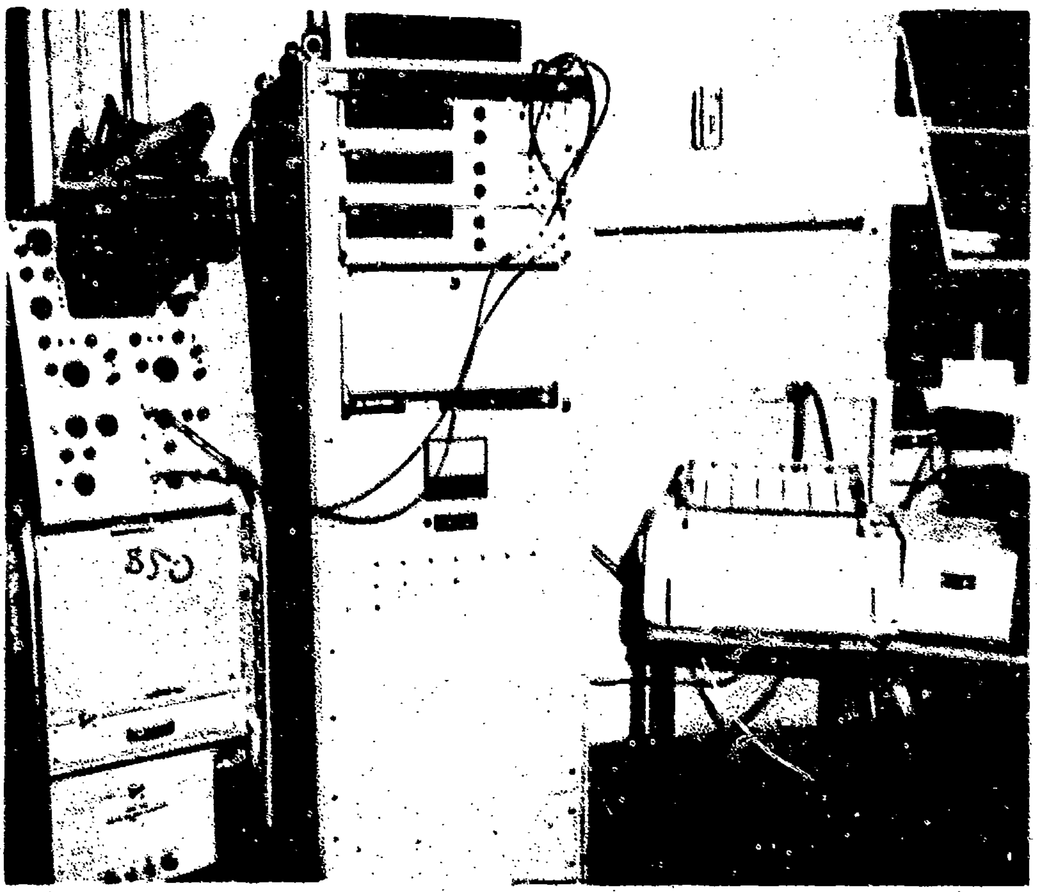

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Figure 12. Air gun-computer interface.

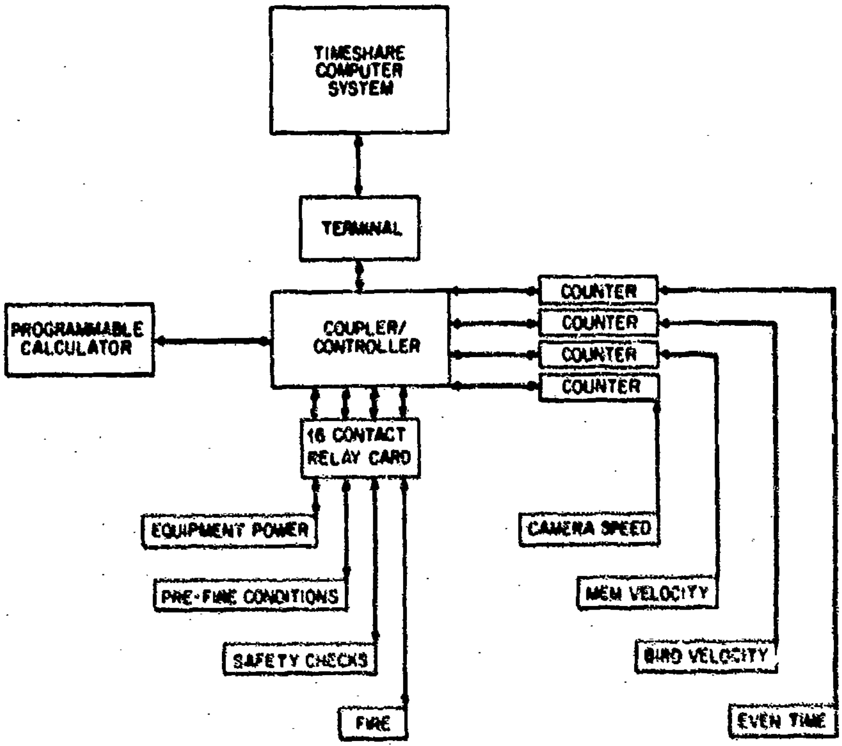

Figure 13. A computer control for the air gun.

The computer interface permits the gun operator to write into computer memory all necessary administrative data records and prefire measurements. This is usually done during the vacuum pump-down procedure. Measurements taken with the timer/counters are automatically recorded into computer memory by this device. Following the gun operator's post-fire entries, the computer produces an immediate test record and lists relevant experimental test parameters that can then be furnished to the test requestor.

4.3 Streak Camera

A Cordin streak camera (model 371) photographically records the displacement-time history of the bird during[2] impact (fig. 14). A 1-1/4-HP motor drives the film drum in its evacuated housing at spins up

[2] *D. J. Mary, Errors in Streak Photography Measurements Caused by Subject and Camera Misalignment, Harry Diamond Laboratories Report HDL-TR-1609 (Aug 1972).*

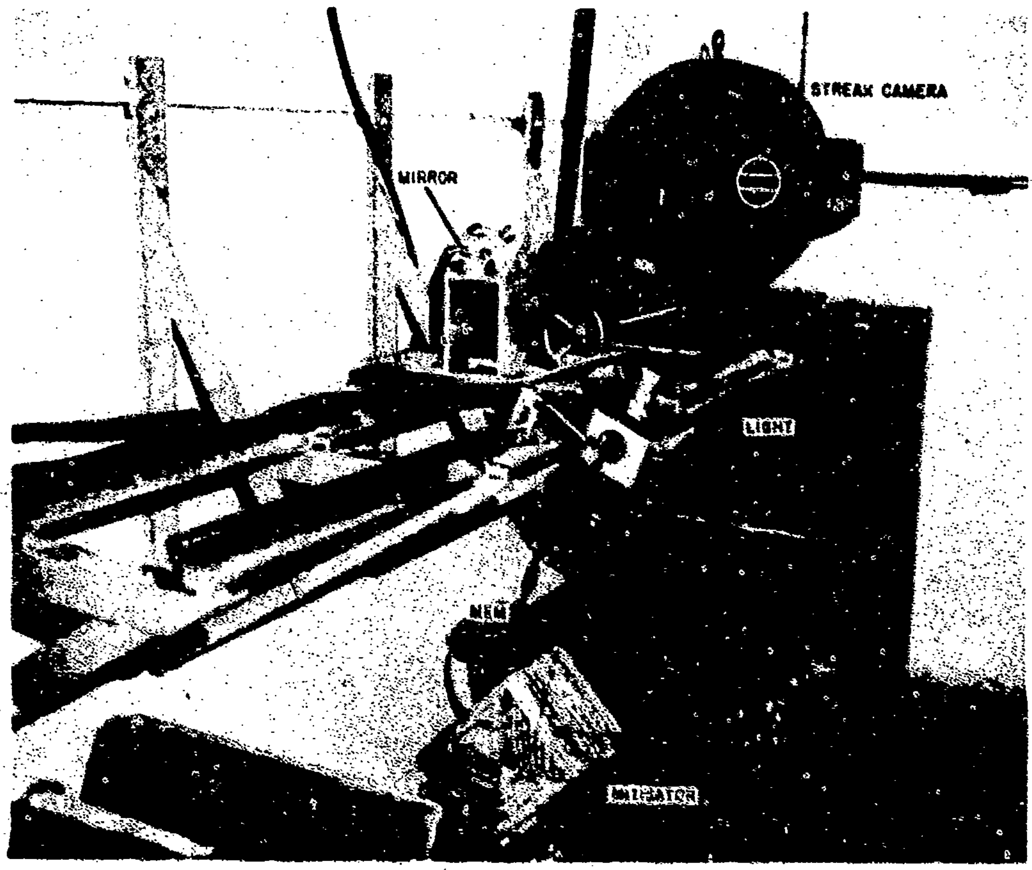

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Figure 14. Streak camera.

to 300 rps. The image of the bird is reflected by a diagonal mirror through an adjustable width slit onto the film. The resulting record is a 70-mm by 1-m streak photograph. Microdensitometer digitized data derived from the streak photograph is finite differenced to produce corresponding velocity and acceleration profiles.

4.4 Microdensitometer

The streak photograph trace is reduced to a digital format with a computer-controlled automated microdensitometer. Standard commercial microdensitometers usually provide maximum stage dimensions 10 by 10 in. A stage of this size could not readily handle the 70-mm by 1-m Cordin streak camera record. Specifications were thus written and this requested. The contract was awarded to Photometric Data Systems Corporation. A film-transport design to handle the required film strip was incorporated as a modification to their standard model 1050 Microdensitometer Data Acquisition System (fig. 15).

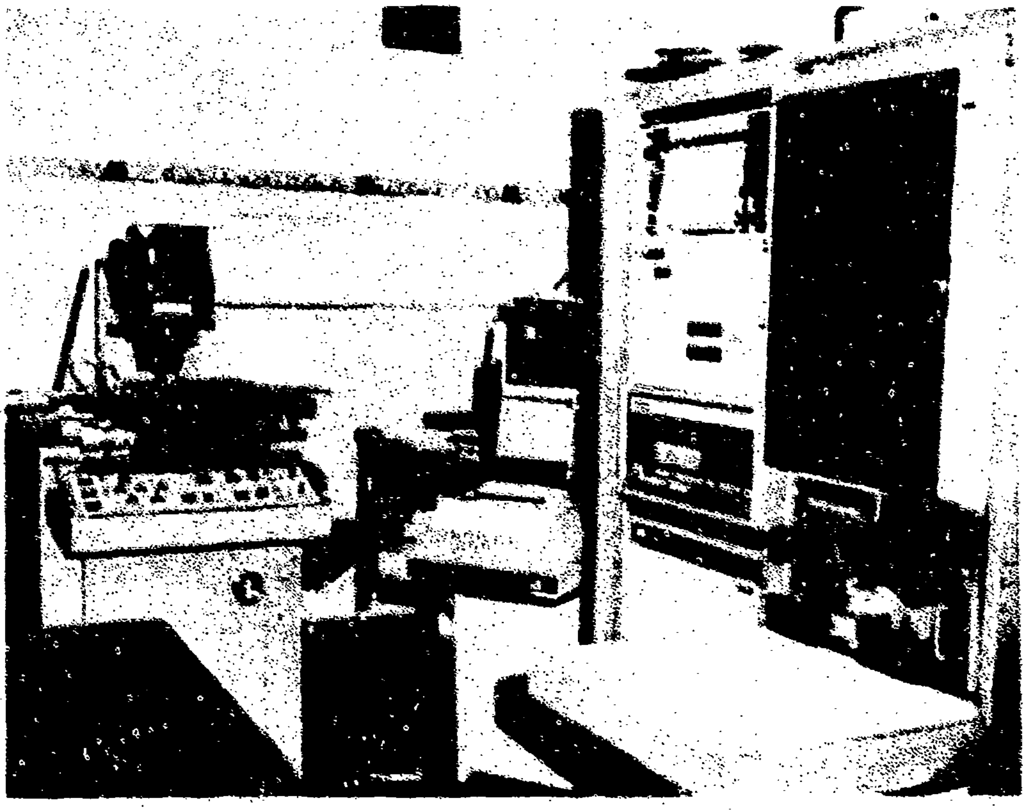

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Figure 15. Microdensitometer system.

The model 1050 microdensitometer may be controlled either manually or by the Digital Equipment Corporation PDP8/M minicomputer, which is interfaced into the film analysis system. I/O devices interfaced to the minicomputer include a Pertec 9 track magnetic tape recorder, Remex high speed paper tape punch/reader, Hewlett Packard 7101 BM strip chart recorder and teletype KSR33. In the automatic mode, 2k two-word data pairs may be acquired during each film scan. A data pair comprises a position coordinate and a density or transmission level. The stage location is measured to 1-μ precision in both time and displacement (scan) axis by linear optical encoders on the microdensitometer and displayed as a six-digit coordinate readout in microns. After each scan is completed, the film transport repositions the stage to the next incremental time position to be read. Also, when a scan is concluded or the data field is filled, the contents of the data field are dumped onto magnetic tape. The digital data on the magnetic tape are later reduced on an IBM 1130 computer to provide the velocity-time, acceleration-time, mitigator stress strain, and force-velocity data and curves.

5. TEST SETUP AND RESULTS

To date, 34 shots have been fired to evaluate gun performance, determine problems, and effect their resolution. These intial tests were also used to check techniques and the precision attained in calculating average test acceleration directly from photocell measurements. The basic computer program used for accessing data, controlling operations, introducing safety delays, and implementing gun firing was formulated, then optimized, during these shots (app D).

5.1 Gun Performance

Projectile velocities of 460 to 530 ft/sec have been attained for bird masses of 5700 to 4300 grams, respectively. Based on this performance level, projectile velocities for the probable range of bird masses (3.25 kilograms considered the minimum bird mass for a reusable bird) can be predicted (fig. 16). Average acceleration levels of 10 to 15 kg over 1.2- to 1.5-msec duration have been attained with marine grade plywood mitigators.

Birds are fired after the gun barrel pressure is reduced to 1 torr. The expansion chamber provides a large volume at the muzzle, minimizing pressure buildup due to compression of air trapped between the bird and the mylar diaphragm.

Subsequent to this test series, the bird was examined visually. No abnormal wear could be seen on the bird lands (bearing surfaces), confirming that the bird passes smoothly across tube joints. An unexpected development did occur, however, in which the bird always rotated in traveling the 98-ft gun length. No definitive explanation was determined for this rotation. Balancing the bird relative to its longitudinal axis did not correct the problem.

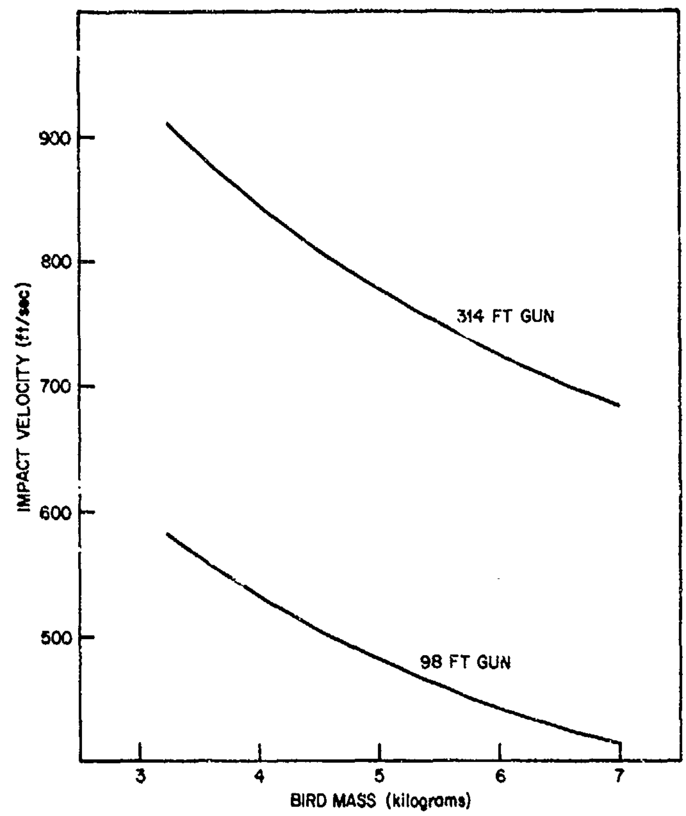

Figure 16. Predicted impact velocity versus bird mass.

5.2 Diaphragm Assembly Performance

While pumping down the gun for the first trial shot, the mylar diaphragm slipped. The air surging back to fill the tube, hurled the bird backward and out of the breech section. It was then observed that one of the Hydra-Dyne hydraulic clamps was not adjusted correctly and that the corner of the mylar sheet adjacent to it slipped into the gun; this problem has recurred twice. It is felt that these failures can be attributed to either misalignment of the hydraulic clamps or an extensive weakening of the mylar itself due to several pump downs followed by vacuum release prior to the gun's firing.

5.3 Catch-Box Action

One problem related to a gun of this size is the necessary controlled dissipation of bird momentum. Since the bird is intended to come to a complete stop shortly after impact, its kinetic energy is absorbed by mitigator crush with excess momentum carried off by the MEM. High-speed motion pictures of the impact showed that with proper ratio of bird mass to total mass of mitigator and MEM, the bird is effectively brought to rest as desired. In the earlier shots, the bird came to rest and then gradually accelerated. This was caused by the propelling air. This effect was minimized by placement of a barrier that disperses the air and also protects the expansion chamber from possible bird rebound.

The MEM must be stopped to prevent damage to catch-box room equipment. Initially, this was attempted by having the MEM impact a stack of lead blocks. This method was far from satisfactory because the lead blocks and MEM were hurled around the room. The problem was corrected by fabrication of a MEM capture box and by staking the lead blocks within this box in a manner that caused the MEM to gradually decelerate and be contained (fig. 8).

5.4 Instrumentation Difficulties

Various problems arose in interfacing the instrumentation to the gun. One problem was premature triggering of the timer/counter from electrical noise. Steps taken to minimize these occurrences included (1) photocell isolation from mechanical vibrations, (2) use of additional decoupling filters in the photocell power-supply line, and (3) setting the trigger level of the time/counter higher than that of the typical noise level generated.

It was found that the vacuum valve produced an ac power surge through one of the program relays of the coupler/controller, which caused improper function. This problem was eliminated by inserting a bypass condenser across the solenoid.

Inconsistent times were recorded for the rotational period of the streak camera. Two factors were involved: (1) the 3-V pulses generated from the camera control unit were comparable in signal level to extraneous noise spikes; (2) a mechanical problem in the camera itself caused inconsistent readings. Until these defects are corrected, a second time/counter will monitor the camera spin.

6. CONCLUSIONS AND RECOMMENDATIONS

Construction and instrumentation of the 7-in. air gun is presently 95-percent complete. This system is now available for interior ballistics simulation. Work has already begun to reconstruct, document, and corroborate tests made for HDL by Motorola's 6-in. air-gun system. Because of instrumentation difficulties, insufficient data have been taken to evaluate the technique of measuring an average acceleration from photocell measurements. Additional work should include (1) a thorough vacuum check while the vacuum system is opened to anchor the pump support table to the floor, (2) an alignment check of all tube sections to evaluate effect of time and usage on alignment and sag, and (3) correction of the mechanical problems associated with the streak camera.

The following recommendations are expected to optimize safety in the existing system and to minimize difficulties in reassembling this gun at the new HDL site.

(1) Fabricate a barrier surrounding the breech section of the gun to insure personnel safety if the mylar diaphagm should fail and the bird is ejected.

(2) Conduct an exact inspection of all remaining tube sections using the laser tooling/alignment system and the spiral wave gauge so that the array of alignment at the new site can be readily determined.

(3) Develop a technique to minimize extraneous effects on the laser system--for example, convection currents in the tube--to minimize difficulties in aligning 314 ft of tube sections.

(4) Check stored tubes periodically to insure that no corrosive or other ill effects are occurring.

APPENDIX A.--REDUCTION OF SPIRAL-WAVE-GAUGE DATA

Tube straightness and bore-diameter variations were computed from spiral-wave-gauge data. The technique used involved measuring local tube bends relative to a line, L_1, between the point of contact of the wheels on the gauge and the inside tube wall (fig. A-1, sect. a). Before measurements were started, the dial indicator was zeroed on a surface plate so that a reading of zero indicated no local bend in the tube. Two sets of readings s_i and s_i' were taken where:

s_i = spiral-wave-gauge reading at each position increment,

s_i' = gauge reading at each position increment with the tube rotated 180 deg.

Bore-diameter variations, b_i, were then computed for each position increment from

$$b_i = \left(s_i + s_i'\right)/2 \qquad i = 1 \text{ to } z \quad , \tag{A-1}$$

where

z = total number of position increments taken.

To compute the slope of the tube relative to a straight line through it, the effect of natural sag and diameter variations were eliminated from the spiral-wave-gauge readings by

$$r_i = \left(s_i - s_i'\right)/2 \qquad i = 1 \text{ to } z, \tag{A-2}$$

where

r_i = resultant local tube bend independent of sag and diameter variations.

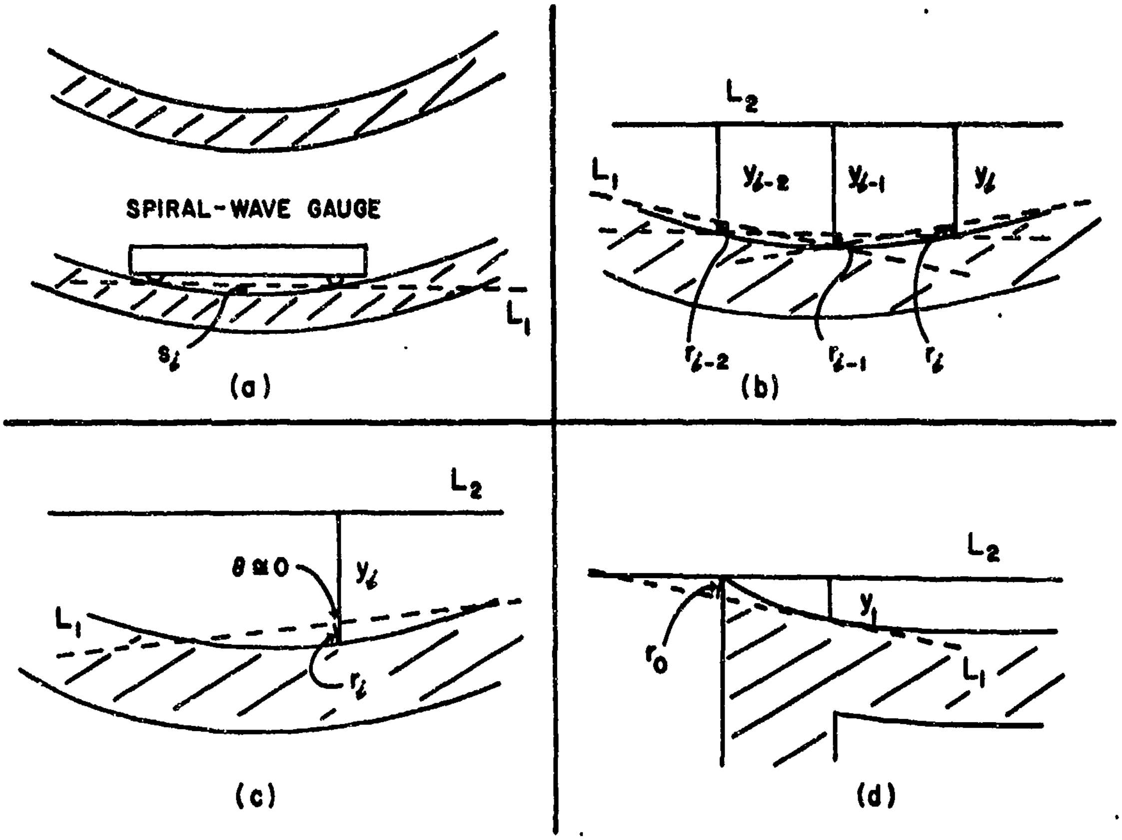

Figure A-1. Spiral-wave-gauge data reduction.

The deviations of the tube, y_i, with respect to any straight line, L_2, through the tube (fig. A-1, sect. b) were then given by

$$y_i = 2\left(y_{i-1} - r_{i-1}\right) - y_{i-2} \quad . \tag{A-3}$$

It is assumed here that this straight line, L_2, is approximately parallel to the local reference line, L_1, determined by the spiral-wave gauge (fig. A-1, sect. c).

To insure that line L_2 passes through the point-of-zero deflection at the tube ends, we solve the following simultaneous equations for an r_o (fig. A-1, sect. d):

$$
\begin{aligned}
y_{-1} &= 0 \\
y_0 &= 0 \\
y_1 &= 2r_o \\
y_2 &= 2\left(y_1 - r_1\right) - y_o \qquad \text{(A-4)} \\
&\cdot \\
&\cdot \\
&\cdot \\
y_z &= 0 = 2\left(y_{z-1} - r_{z-1} - y_{z-2}\right) ,
\end{aligned}
$$

which gives

$$
r_o = \sum_{i=1}^{z} (z-i)\, r_i / z \ . \qquad \text{(A-5)}
$$

APPENDIX B.--REDUCTION OF LASER DATA

To reconstruct the bore-diameter variations of a tube from the inspection data, all influence of natural sag from its own weight has to be eliminated. The deflection from the centerline of a simply supported tube (fig. B-1) is as follows.

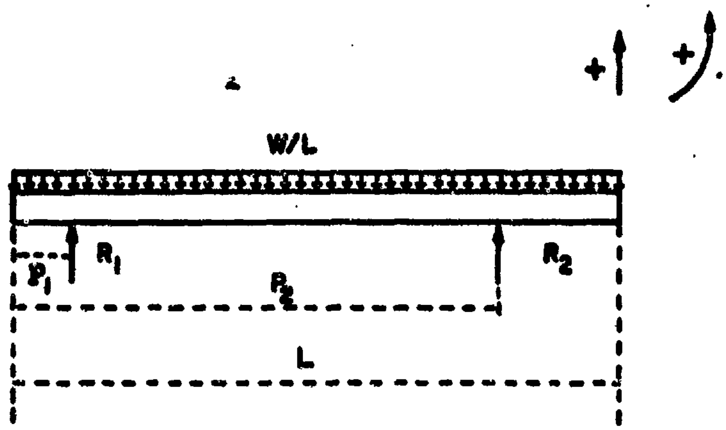

Figure B-1. Simply supported tube section.

Let

R_1, R_2 = reaction forces of stands 1 and 2 used in inspection

W = weight of tube

L = tube length

p_1, p_2 = position of stands 1 and 2.

Solving for the reaction forces,

$$R_1 = W(p_2 - 0.5L)/(p_2 - p_1) \tag{B-1}$$

$$R_2 = W(0.5L - p_1)/(p_2 - p_1) . \tag{B-2}$$

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APPENDIX B

We then solve for the bending moments

$$M = EId^2v(x)/dx^2 \tag{B-3}$$

where

M = bending moment,

E = Young's modulus,

I = moment of inertia of tube,

x = position from end 0, and

$v(x)$ = vertical deflection of tube at position x.

For $0 \leq x \leq p_1$, the bending moments equation becomes

$$d^2v(x)/dx^2 = -Wx^2/2EIL \ ; \tag{B-4}$$

which integrates to

$$dv(x)/dx = dv(0)/dx - Wx^3/6EIL \tag{B-5}$$

$$v(x) = v(0) + dv(0)/dx \cdot x - Wx^4/24EIL. \tag{B-6}$$

Similarly, for $p_1 \leq x \leq p_2$,

$$d^2v(x)/dx^2 = -Wx^2/2EIL + R_1\left(x-p_1\right)/EI \tag{B-7}$$

$$dv(x)/dx = dv\left(p_1\right)/dx + W\left(p_1{}^3-x^3\right)/6EIL + R_1\left(x^2 + p_1{}^2-2xp_1\right)/2EI \tag{B-8}$$

$$v(x) = v\left(p_1\right) + dv\left(p_1\right)/dx\cdot\left(x-p_1\right) + W\left(4p_1{}^3\cdot x-x^4 - 3p_1{}^4\right)/24EIL + R_1\left(x^3 - 3p_1\, x^2 + 3p_1{}^2\, x-p_1{}^3\right)/6EI \ . \tag{B-9}$$

For $p_2 \leq x \leq L$,

$$d^2v(x)/dx^2 = -Wx^2/2EIL + R_1\left(x-p_1\right)/EI + R_2\left(x-p_2\right)/EI \quad \text{(B-10)}$$

$$\begin{aligned} dv(x)/dx &= dv\left(p_2\right)/dx + W\left(p_2{}^3-x^3\right)/6EIL + \\ &\quad R_1\left(x^2-2p_1\, x-p_2{}^2 + 2p_1\, p_2\right)/2EI + \\ &\quad R_2\left(x^2 - 2p_2\, x+p_2{}^2\right)/2EI\ ; \end{aligned} \quad \text{(B-11)}$$

$$\begin{aligned} v(x) &= v\left(p_2\right) + dv\left(p_2\right)/dx\cdot\left(x-p_2\right) + \\ &\quad W\left(4p_2{}^3\, x-x^4 - 3p_2{}^4\right)/24EIL + \\ &\quad R_1\left(x^3 - 3p_1\, x^2 - 3p_2{}^2\, x + 6p_1\, p_2\, x+2p_2{}^3 - 3p_1\, p_2{}^2\right)/6EI + \\ &\quad R_2\left(x^3 -3p_2\, x^2 +3p_2{}^2\, x-p_2{}^3\right)/6EI. \end{aligned} \quad \text{(B-12)}$$

For the simply supported tube, the following boundary conditions hold:

$$\begin{aligned} v\left(p_1\right) &= 0 \\ v\left(p_2\right) &= 0. \end{aligned} \quad \text{(B-13)}$$

The bending moment equations contain the following unknowns:

$$v(0),\ dv(0)/dx,\ dv\left(p_1\right)/dx,\ dv\left(p_2\right)/dx. \quad \text{(B-14)}$$

Substituting $x=p_2$ into equation (B-9) allows us to solve for $dv\left(p_1\right)/dx$:

$$\begin{aligned} dv\left(p_1\right)/dx = \Big[& W\left(p_2{}^4-4p_1{}^3\, p_2+3p_1{}^4\right)/24EIL + \\ & R_1\left(3p_1\, p_2{}^2-p_2{}^3 -3p_1{}^2p_2 +p_1{}^3\right)/6EI \Big] / \left(p_2-p_1\right). \end{aligned} \quad \text{(B-15)}$$

Combining equations (B-15) and (B-5) allows us to solve for $dv(0)/dx$:

$$dv(0)/dx = dv\left(p_1\right)/dx + Wp_1{}^3/6EIL. \quad \text{(B-16)}$$

We may then solve equation (B-6) for v(0):

$$v(0) = -dv(0)/dx \cdot p_1 + Wp_1^4/24EIL. \qquad \text{(B-17)}$$

Solving equation (B-8) for $x=p_2$ gives

$$dv(p_2)/dx = dv(p_1)/dx + R_1 (p_1-p_2)^2/2EI - W(p_2^3-p_1^3)/6EIL. \qquad \text{(B-18)}$$

We now have expressions for the deflection of the tube due to its own weight as a function of position from one end and the location of the support stands. In this analysis, the weights of the flanges are neglected since their effect was found to be negligible.

This technique required two sets of laser readings to reconstruct the shape of the tube, one taken with the tube rotated 180 deg relative to the other. The positions of the stands had to remain the same and for each set, and readings over each stand were required. It was also required that both sets of readings be taken with respect to the same optical axis. Since it is known that the tube does not deflect over the stands, both sets of readings can be transformed by

$$q(x) = w(x) - \left[(w_1-w_2)(x-p_1)/(p_1-p_2) + w_1\right] \qquad \text{(B-19)}$$

where

$q(x)$ = transformed laser reading relative to line through points of zero deflection over stands

$w(x)$ = laser reading at position x

w_1 = laser reading over stand 1

w_2 = laser reading over stand 2.

Similarly,

$$q'(x) = w'(x) - \left[(w_1'-w_2')(x-p_1)/(p_1-p_2) + w_1'\right], \qquad \text{(B-20)}$$

where

$q'(x)$ = transformed laser reading with tube rotated 180 deg

$w'(x)$ = laser reading taken with tube rotated 180 deg etc.

The bore-diameter variation of the tube, $b(x)$, now becomes

$$b(x) = q(x) + q'(x) - 2v(x). \tag{B-21}$$

The variation of the tube with respect to the line through the stands becomes

$$z(x) = \left[q(x)-q'(x)\right]/2 \; , \tag{B-22}$$

where

$z(x)$ = tube variation without sag.

Since we were concerned with the shape of the tube with respect to an optical axis through the center points of each end, we must subtract a line from the results so that no deflection is read at the endpoints. That is,

$$u(x) = z(x) - \left[\left(z(l)-z(0)\right)x/L + z(0)\right] \; , \tag{B-23}$$

where

$u(x)$ = deviation from optical axis through the center points of each end.

APPENDIX C.--COMPUTATION OF AVERAGE ACCELERATION FROM PHOTOCELL MEASUREMENTS

Figure C-1 is a trace of the paths of the bird and MEM during the ballistics simulation where

$S_1 = X_2 - X_1$ = separation of photocells in expansion chamber,

$S_2 = X_7 - X_6$ = separation of photocells mounted behind MEM,

$t_1 = T_2 - T_1$ = time required to trigger photocells in expansion chamber,

$t_2 = T_7 - T_6$ = time required to trigger both photocells behind the MEM,

$T = T_4 - T_3$ = time required for initial stress wave generated at impact to reach MEM.

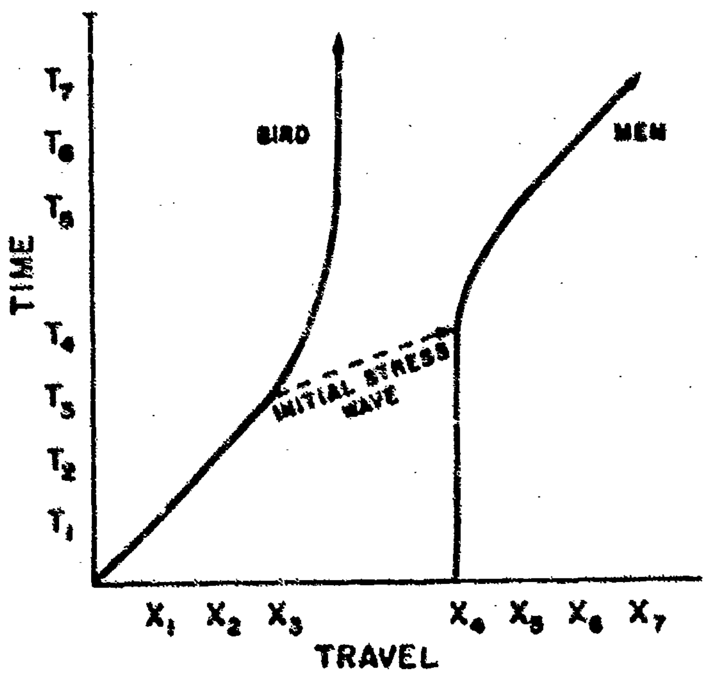

Figure C-1. Position-time history of bird and MEM during ballistics simulation.

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APPENDIX C

The path of the MEM before it reaches the photocell at X_6 may be broken into two regions:

$Y_1 = X_5 - X_4$ = region over which MEM accelerates,

$$Y_1 = S_2\left(T_5 - T_4\right)/2t_2 \quad , \tag{C-1}$$

and

$Y_2 = X_6 - X_5$ = region after MEM stops acceleration but before it reaches photocell at X_6,

$$Y_2 = S_2\left(T_6 - T_5\right)/t_2 \quad . \tag{C-2}$$

The total path taken by the MEM then becomes

$$Y = Y_1 + Y_2 \quad , \tag{C-3}$$

$$Y = S_2\left(T_6 - 0.5T_5 - 0.5T_4\right)/t_2 \quad . \tag{C-4}$$

The impact time, Δt, is

$$\Delta t = T_5 - T_3 \quad . \tag{C-5}$$

Therefore,

$$T_5 = \Delta t + T_3 \quad , \tag{C-6}$$

and

$$Y = S_2\left(T_6 - 0.5\Delta t - 0.5T_3 - 0.5T_4\right)/t_2 \quad . \tag{C-7}$$

But

$$T_4 = T_3 + T, \tag{C-8}$$

$$T_3 = T_2 + \left(X_3 - X_2\right)/\left(S_1/t_1\right) \quad . \tag{C-9}$$

Substituting equations (C-8) and (C-9) into (C-7) gives

$$Y = S_2\left[T_6 - T_2 - \Delta t/2 - \left(X_3 - X_2\right)/\left(S_1/t_1\right) - T/2\right]/t_2 \quad , \tag{C-10}$$

and

$$\Delta t = -2\left[Yt_2/S_2 - \left(T_6 - T_2\right) + t_1\left(X_3 - X_2\right)/S_1 + T/2\right] \qquad \text{(C-11)}$$

where

T, Y, S_1, S_2 $\left(X_3 - X_2\right)$ are known before the test;

t_1, t_2, $\left(T_6 - T_2\right)$ are measured with photocells.

The average acceleration level then is given by

$$a = \left(V_2 - V_1\right)/\Delta t \quad . \qquad \text{(C-12)}$$

where

a = average bird acceleration,

V_1 = impact velocity of the bird,

$V_1 = S_1/t_1$, (C-13)

V_2 = final bird velocity which is given by conservation of momentum;

$V_2 = \left(m_1V_1 - m_2U_2\right)/m_2$, (C-14)

m_1 = bird weight,

m_2 = MEM plus mitigator weight,

U_2 = MEM and mitigator velocity,

$U_2 = S_2/t_2$.

APPENDIX D. CONTROLLER AND DATA REDUCTION PROGRAMS FOR THE 7-IN. AIR GUN

SEVEN.O.

```
10 REM
20 REM      THIS PROGRAM GENERATES THE COMMANDS REQUIRED FOR
30 REM      THE FIRING OF THE SEVEN INCH AIR GUN.
40 REM
50 DIM W(11),L(11)
60 MAT READ W(11)
70 DATA 25863,21143,19623,13449,6466,20838,24618
80 DATA 10669,10442,13393,13620
90 MAT READ L(11)
100 DATA 4,3.27,3.035,2.08,1,2.04,2.375
110 DATA 1,1,1.25,1.25
120 FILES TEMPY.O.
130 PRINT "TURN ON VACUUM PUMP AND START CAMERA."
140 PRINT "HIT 'RETURN' WHEN READY TO GO."     'START FIRING SEQUENCE.
150 PRINT
160 MAT INPUT X
170 X9=NUM
180 IF X9<>0 THEN 270
190 PRINT "CON"
200 PRINT "@5N0001"      'COMMAND TO COUPLER/CONTROLLER
210 PRINT "COF"          'TO START VACUUM PUMPDOWN.
220 PRINT "VACUUM BEING PULLED ....STAY CLEAR OF BREECH"
230 PRINT
240 REM
250 REM     DURING PUMPDOWN TEST DATA IS ENTERED BY THE OPERATOR.
260 REM
270 PRINT "INPUT SHOT #"
280 PRINT
290 INPUT S1
300 PRINT "PROJECT #"
310 PRINT
320 INPUT M$
330 PRINT "TEST REQUESTOR"
340 PRINT
350 INPUT N$
360 IF LEN(M$)=6 THEN 410
370 PRINT "IMPROPER PROJECT #.  ENTER # AGAIN."
380 PRINT
390 INPUT M$
400 GOTO 360
410 PRINT "BIRD #"
420 PRINT
430 INPUT B1
440 PRINT "NOSE SHAPE CODE"
450 PRINT
460 INPUT N9
470 IF N9<3 THEN 490
480 GOSUB 1800
490 PRINT "GUN OPERATOR CODE"
500 PRINT
```


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APPENDIX D

SEVEN.O.

```
510 INPUT O1
520 IF O1<= 7 THEN 540
530 GOSUB 1800
540 PRINT "INPUT BIRD WEIGHT (GRAMS)"
550 PRINT
560 INPUT W1
570 PRINT "MEM CODE"
580 PRINT
590 MAT INPUT H$
600 SO=NUM
610 IF NUM>0 THEN 690
620 PRINT "INPUT MEM WEIGHT (GRAMS)"
630 PRINT
640 INPUT W2
650 PRINT "INPUT MEM WIDTH (INCHES)"
660 PRINT
670 INPUT L7
680 GOTO 810
690 FOR K=1 TO SO
700 FOR J=1 TO LEN(H$(K))
710 FOR I=1 TO 11
720 IF EXT$(H$(K),J,J)<>EXT$("ABCDEFGHIJK",I,I) THEN 750
730 W2=W2+W(I)
740 L7=L7+L(I)
750 NEXT I
760 NEXT J
770 NEXT K
780 IF W2>0 THEN 810
790 GOSUB 1800
800 GOTO 620
810 PRINT "BAFFLE DIAMETER"
820 PRINT
830 INPUT H1
840 PRINT "MITIGATOR CODE"
850 PRINT
860 INPUT N1
870 IF N1<=11 THEN 890
880 GOSUB 1800
890 PRINT "INITIAL MITIGATOR LENGTH (INCHES)"
900 PRINT
910 INPUT L1
920 PRINT "MITIGATOR WEIGHT (GRAMS)"
930 PRINT
940 INPUT W3
950 PRINT "INPUT MITIGATOR-MEM POSITION (INCHES)"
960 PRINT
970 INPUT C7
980 C7=C7/12
990 X7=16.18/12+C7
1000 Y7=62.31/12-16.18/12-C7-L1/12-L7/12
1010 PRINT "CAMERA OPERATOR CODE"
1020 PRINT
```

SEVEN.O.

```
1030 INPUT O2
1040 IF O2=0 THEN 1140
1050 IF O2<=7 THEN 1070
1060 GOSUB 1800
1070 PRINT "DISTANCE FROM NOSE TO FIRST STRIPE (INCHES)"
1080 PRINT
1090 INPUT L3
1100 PRINT "PROBE STANDOFF DISTANCE (CENTIMETERS)"
1110 PRINT
1120 INPUT L4
1130 PRINT
1140 O1=O1/10
1150 O2=O2/100
1160 N1=N1+O1+O2
1170 IF X9<>0 THEN 1440
1180 REM
1190 REM   PRE-FIRE DATA ENTRY COMPLETE.  CHECK FOR DESIRED
1200 REM   VACUUM AND PROPER PHOTOCELL VOLTAGES.
1210 REM
1220 PRINT "VACUUM AND LIGHTS BEING CHECKED"
1230 PRINT "CON"
1240 PRINT "@2C"     'CONTINUE IF DESIRED VACUUM AND PHOTOCELL
1250 INPUT Z         'VOLTAGES REACHED.
1260 PRINT "COF"
1270 PRINT "GUN IS NOW READY TO FIRE!"
1280 PRINT
1290 PRINT "TYPE 'FIRE' TO FIRE GUN"
1300 PRINT
1310 INPUT F$
1320 IF EXT$(F$,1,4)<>"FIRE" THEN 1630
1330 CALL BREAK (0)
1340 PRINT "CON"
1350 PRINT "@5N0000"
1360 PRINT "[@4E@3E@6L"
1370 PRINT "@5N0084]"      'ENABLE COUNTERS AND FIRE GUN.
1380 REM
1390 REM     GUN FIRED.  READ COUNTERS AND CLOCK.
1400 REM
1410 PRINT "TIME OF SHOT (##:##)"
1420 PRINT "@0I@6M"
1430 INPUT D$
1440 PRINT "CAMERA TIME"
1450 PRINT "@0I@30"
1460 INPUT S
1470 PRINT "@5N0000"
1480 PRINT "PHOTOCELL TIME"
1490 PRINT "@0I@40"
1500 INPUT T
1510 PRINT "COF"
1520 CALL BREAK(1)
1530 IF O2=0 THEN 1600
1540 IF S=0 THEN 1600
```

APPENDIX D

SEVEN.O.

```
1550 S3=1E6/S
1560 REM
1570 REM      ALL DATA IS NOW STORED IN A TEMPORARY FILE AND
1580 REM      THE PROGRAM "FIVE.O." IS CALLED.
1590 REM
1600 SCRATCH:1
1610 WRITE:1,S1,N$,M$,B1,N9,W1,W2,H1,N1,L1,W3,L4,L3,S3,T,D$,X7,Y7,X9
1620 CHAIN "FIVE.O."
1630 PRINT "CON"
1640 PRINT "@5N0009"
1650 PRINT "COF"
1660 PRINT "GUN SEQUENCE HAS BEEN STOPPED."
1670 PRINT "TYPE 'CONT' TO CONTINUE."
1680 PRINT
1690 INPUT F$
1700 IF EXT$(F$,1,4)<>"CONT" THEN 1750
1710 PRINT "CON"
1720 PRINT "@5N0001"
1730 PRINT "COF"
1740 GOTO 1220
1750 PRINT"GUN SHUT DOWN"
1760 PRINT "CON"
1770 PRINT "@5N0000@5N0002"
1780 PRINT"COF"
1790 STOP
1800 PRINT
1810 PRINT "PROGRAM DOES NOT RECOGNIZE THIS CODE.";
1815 PRINT "  PROCEED BUT INFORM OTTEN."
1820 RETURN
1830 END
```

FIVE.O.

```
10 REM
20 REM      THIS PROGRAM READS THE DATA STORED BY "SEVEN.O."
30 REM      AND GENERATES A PRINTOUT OF THE TEST RESULTS.
40 REM
50 DIM E(12)
60 FOR I=1 TO 12
70 E(I)=1200
80 NEXT I
90 E(1)=E(5)=E(6)=18000
100 FILES TEMPY.O.;SHOTS7
110 READ:1,S1,N$,M$,B1,N9,W1,W2,H1,N1,L1,W3,L4,L3,S3,T,D$,X7,Y7,X9
120 PRINT S3,T,D$
130 PRINT "SET TAB AT 10 THEN HIT CR."
140 INPUT
150 E$=DAT$
160 IF X9=0 THEN 200
170 PRINT"ENTER DATE OF SHOT (##/##/##)"
180 PRINT
190 INPUT E$
200 DIM A$(15)
210 DEF FNA$(A,Z$)
220 O(0)=10
230 O$=STR$(A)
240 O$=Z$+Z$+Z$+O$
250 O$=EXT$(O$,LEN(O$)-3,LEN(O$))
260 IF EXT$(O$,2,2)<>"-" THEN 280
270 O$=EXT$(O$,2,2)+EXT$(O$,1,1)+EXT$(O$,3,4)
280 PRINT O$
290 FNEND
300 B(B(0)= 1)=10
310 CHANGE B TO B$
320 DEF FNB$(N)
330 FOR I=1 TO N
340 PRINT   B$;
350 NEXT I
360 FNEND
370 REM
380 REM      ENTER POST-FIRE DATA.
390 REM
400 IF INT(N1)=9 THEN 420
410 IF INT(N1)<>11 THEN 500
420 R4=1
430 PRINT "INPUT # OF MITIGATOR SECTIONS"
440 PRINT
450 INPUT N3
460 PRINT"INPUT CRUSHED LENGTHS (INCHES) FOR EACH SECTION ";
465 PRINT"(##.##,##.##,.....)"
470 PRINT
480 MAT INPUT L(N3)
490 IF INT(N1)=9 THEN 530
500 PRINT "INPUT TOTAL CRUSHED MITIGATOR LENGTH (INCHES)"
510 PRINT
```

APPENDIX D

FIVE.O.

```
520 INPUT L2
530 PRINT "INPUT MEM TIME"
540 PRINT
550 INPUT T7
560 PRINT "INPUT EVENT TIME"
570 PRINT
580 INPUT T8
590 PRINT "DO YOU WISH TO CORRECT CAMERA SPEED"
600 PRINT
610 INPUT Y$
620 IF EXT$(Y$,1,1)<>"Y" THEN 660
630 PRINT "INPUT CAMERA SPEED (RPS)"
640 PRINT
650 INPUT S3
660 PRINT "COMMENTS"
670 PRINT
680 MAT INPUT V$
690 N7=NUM
700 IF N9<3 THEN 740
710 PRINT "DESCRIBE NOSE SHAPE"
720 PRINT
730 INPUT M$(N9)
740 IF O1<= 7 THEN 780
750 PRINT "INPUT GUN OPERATOR'S NAME"
760 PRINT
770 INPUT N$(O1)
780 IF O2<=7 THEN 820
790 PRINT "INPUT CAMERA OPERATOR'S NAME"
800 PRINT
810 INPUT N$(O2)
820 IF N1<=11.99 THEN 860
830 PRINT "INPUT MITIGATOR TYPE"
840 PRINT
850 INPUT A$(N1)
860 A$(5)="HONEYCOMB"
870 A$(6)="SHAPED HONEYCOMB"
880 A$(1)="SHAPED TUBECORE"
890 A$(7)="7.875 X 7.875 MARINE PLYWOOD"
900 A$(11)="9X9 MARINE PLYWOOD"
910 A$(8)="SHAPED 7.875 X 7.875 MARINE PLYWOOD"
920 A$(9)="SHAPED 9X9 MARINE PLYWOOD"
930 MAT READ N$(7)
940 DATA KAYSER,MEEKS,BALL,SMITH,CURCHACK,BERRY,MARY
950 M$(1)="FLAT NOSE"
960 M$(2)="6 INCH DIAMETER FLAT NOSE"
970 REM
980 REM     OUTPUT RESULTS.
990 REM
1000 PRINT
1010 PRINT"-----"
1020 I$=FNB$(5)
```

FIVE.O.

```
1030 PRINT
1040 PRINT "7-INCH AIR GUN TEST RESULTS"
1050 PRINT "---------------------------"
1060 PRINT
1070 PRINT "SHOT # "S1,E$,"(";D$;")"
1080 PRINT
1090 PRINT "TEST PERFORMED FOR MR. ";N$,"(";M$;")"
1100 PRINT
1110 PRINT "PROJECTILE # ";B1;" (";M$(N9);")"
1120 PRINT USING 1130,W1
1130 :           BIRD WEIGHT              ####* GRAMS
1140 PRINT "GUN (SEVEN INCH)"
1150 PRINT USING 1160
1160 :           FIRING PRESSURE            .00 PSIG
1170 PRINT USING 1180
1180 :           VACUUM WAS USED
1190 PRINT USING 1200,T
1200 :           PHOTOCELL TIME           ##### MICROSEC
1210 IF T=0 THEN 1280
1220 REM
1230 REM    CHECK FOR PROPER PHOTOCELL TIME.
1240 REM
1250 V=1E6/T
1260 IF V>1500 THEN 1280
1270 IF V>100 THEN 1310
1280 PRINT USING 1290
1290 :           PHOTOCELL TIME INCORRECT.  ESTIMATED VALUE USED.
1300 F9=1
1310 IF INT(H1)<>7 THEN 1490
1320 W6=W1/454
1330 K=32.2*14.7*3.14159*49*98/W6/2
1340 V1=SQR(K)
1350 X=K/2/1128/1128
1360 R=(X*(X*(X*(X*(-1.11783E-3)+.018604)-.112361)+.312049)-.469038)
1365 R=X*R+.996007
1370 V2=R*V1
1380 IF F9=0 THEN 1410
1390 V=.9*V2
1400 GOTO 1490
1410 P=V/V2*100
1420 E6=V/V1*100
1430 PRINT USING 1440,E6
1440 :           EFFICIENCY             ###.# %
1450 PRINT USING 1460,X
1460 :           NON-DIMENSIONAL LENGTH #.###
1470 PRINT USING 1480,P
1480:            GUN PERFORMANCE        ###.# %
1490 O1=INT(10*N1)-10*INT(N1)
1500 O2=INT(100*N1+.5)-10*INT(10*N1)
1510 PRINT USING 1520,N$(O1)
1520 :           TEST PERFORMED BY MR. 'E
1530 PRINT "MITIGATOR WAS ";A$(N1)
```

APPENDIX D

FIVE.O.

```
1540 PRINT USING1550,W3
1550 :          MITIGATOR WEIGHT          ##### GRAMS
1560 PRINT USING 1570,L1
1570 :          INITIAL MITIGATOR LENGTH ##.## INCHES
1580 IF INT(N1)=9 THEN 1600
1590 IF INT(N1)<>11 THEN 1690
1600 PRINTUSING 1610,N3
1610 "          MITIGATOR SEPARATED INTO    ## PIECES
1620 PRINT"           (";
1630 FOR I=1 TO N3
1640 PRINT USING 1650,L(I);
1650 :#.##,
1660 NEXT I
1670 PRINT "INCHES)"
1680 IF INT(N1)=9 THEN 1710
1690 PRINT USING 1700,L2
1700 :          CRUSHED MITIGATOR LENGTH ##.## INCHES
1710 PRINT "MOMENTUM EXCHANGE MASS"
1720 PRINT USING 1730,W2
1730 :          MEM WEIGHT                ##### GRAMS
1740 IF T7=0 THEN 1800
1750 PRINT USING 1760,T7
1760 :          MEM PHOTOCELL TIME        ##### MICROSEC
1770 V7=5E5/T7
1780 PRINT USING 1790,V7
1790 :          MEM VELOCITY              ###.# FT/SEC
1800 IF S3=0 THEN 1970
1810 L5=L4-L3
1820 PRINT"HIGH SPEED STREAK CAMERA"
1830 PRINT USING 1840,S3
1840 :          STREAK CAMERA SPIN        ###.# RPS
1850 PRINT USING 1860,L5
1860 :          CAMERA LOCATION           ##.## INCHES
1870 PRINT USING 1880,N$(02)
1880 :          CAMERA OPERATED BY MR. 'E
1890 PRINT "COMMENTS"
1900 IF INT(H1)=7 THEN 1930
1910 PRINT "           A ";H1;" INCH DIAMETER RESTRICTION WAS EMPLOYED"
1920 PRINT"              AT THE BREECH TO RESTRICT MUZZLE VELOCITY."
1930 FOR I=1 TO N7
1940 PRINT "           "+V$(I)
1950 NEXT I
1960 PRINT
1970 PRINT "RESULTS"
1980 IF INT(N1)=9 THEN 2260
1990 PRINT "   CRUSH MEASUREMENT:"
2000 G6=454*14.7/W1*49.4*3.14159/4
2010 PRINT USING 2020,G6
2020 :          MAX LAUNCH G              ###.#  G
2030 X=L1-L2
2040 L2=0
2050 FOR I=1 TO LEN(A$(N1))-3
```

FIVE.O.

```
2060 IF EXT$(A$(N1),I,I+3)="WOOD" THEN 2090
2070 NEXT I
2080 GOTO 2100
2090 X=(1.14*X+8.5E-2*L1*(1-EXP(-11*X/L1)))
2100 X=X*(W1+W2+W3)/(W2+W3)
2110 G=(V*V/X)*.186335      'AVERAGE BIRD ACCELERATION CALCULATED
2120 PRINT USING 2130,X     'FROM MITIGATOR CRUSH.
2130 :           STOPPING DISTANCE        ##.## INCHES
2140 PRINT USING 2150,V
2150 :           IMPACT VELOCITY          ###.# FT/SEC
2160 G1=100*INT(G/100)
2170 PRINT USING 2180,G1
2180 :           AVERAGE ACCELERATION     ##### G
2190 T9=(V/G)*31.1
2200 PRINT USING 2210,T9
2210 :           IMPACT TIME              ##.## MILLISEC
2220 IF F9=0 THEN 2260
2230 PRINT "RESULTS BASED ON ESTIMATED PHOTOCELL TIME."
2240 PRINT "SEE FILM REPORT FOR CORRECT VALUES."
2250 G=V=0
2260 IF R5=1 THEN 2440
2270 PRINT "   PHOTOCELL MEASUREMENTS:"
2280 IF T8=0 THEN 2440
2290 IF T7=0 THEN 2440
2300 PRINT USING 2310,T8
2310 :           EVENT PHOTOCELL TIME     ##### MICROSEC
2320 D7=-2*(Y7*T7/5E5+X7*T/1E6-T8/1E6)-L1/12/E(N1)
2330 V5=(W1*V-(W2+W3/2)*V7)/(W1+W3/2)
2340 G7=(V-V5)/D7/32.2      'AVERAGE BIRD ACCELERATION CALCULATED
2350 D7=D7*1000             'FROM PHOTOCELL MEASUREMENTS.
2360 G7=100*INT(G7/100)
2370 PRINT USING 2380,G7
2380 :           AVERAGE ACCELERATION     ##### G
2390 PRINT USING 2400,V5
2400 :           FINAL BIRD VELOCITY     ####.# FT/SEC
2410 PRINT USING 2420,D7
2420 :           IMPACT TIME              ##.## MILLISEC
2430 IF R4=1 THEN 2860
2440 I$=FNB$(15)
2450 PRINT "-----"
2460 IF S3=0 THEN 2820
2470 REM
2480 REM     PRINT INFORMATION REQUIRED FOR STREAK FILM ANALYSIS.
2490 REM
2500 PRINT
2510 PRINT "SHOT # ";S1
2520 PRINT M$
2530 U9=INT(50*S3+.5)
2540 PRINT"READ FILM AT INCREMENTS OF ";U9;" MICRONS"
2550 U8=INT(25400/U9+.5)+1
2560 PRINT"# OF SCANS PER INCH ";U8
2570 I$=FNB$(5)
```

APPENDIX D

FIVE.O.

```
2580 I$=FNA$(S1,"-")
2590 E9=INT(LOG(LI)/LOG(10))
2600 N5=INT(L1*10^(2-E9)+E9*1E3+.5)
2610 I$=FNA$(N5,"0")
2620 N5=INT(S3*10+.5)
2630 I$=FNA$(N5,"0")
2640 E9=INT(LOG(W1)/LOG(10))
2650 W4=(W2+W3)/W1
2660 N5=INT(W1*10^(2-E9)+E9*1E3+.5)
2670 I$=FNA$(N5,"0")
2680 N5=INT(100*L5+.5)
2690 I$=FNA$(N5,"0")
2700 W4=INT(100*W4+.5)
2710 I$=FNA$(W4,"0")
2720 PRINT "21"
2730 I$=FNB$(5)
2740 PRINT"-----"
2750 PRINT "OK TO FILE"
2760 PRINT
2770 INPUT Z$
2780 IF EXT$(Z$,1,1)<>"Y" THEN 2930
2790 REM
2800 REM     STORE DATA IN PERMANENT FILE.
2810 REM
2820 APPEND:2
2830 WRITE:2,S1;DAT$;M$;N$;W1;W2;S3;N1;V;G;B1;L1;X;L5;N9;W3
2840 PRINT "NEW DATA FILED"
2850 STOP
2860 FOR I=1 TO N3
2870 L2=L2+L(I)
2880 NEXT I
2890 PRINT "   MOTOROLA TECHNIQUE:"
2900 R4=0
2910 R5=1
2920 GOTO 2000
2930 PRINT "FILE NOT CHANGED"
2940 END
```

SEVEN.O.

TURN ON VACUUM PUMP AND START CAMERA.
HIT 'RETURN' WHEN READY TO GO.

?
CON
VACUUM BEING PULLED ....STAY CLEAR OF BREECH

INPUT SHOT #

? 28
PROJECT #

? 639235
TEST REQUESTOR

? OTTEN
BIRD #

? 4
NOSE SHAPE CODE

? 1
GUN OPERATOR CODE

? 3
INPUT BIRD WEIGHT (GRAMS)

? 5740
MEM CODE

? F
BAFFLE DIAMETER

? 5
MITIGATOR CODE

? 7
INITIAL MITIGATOR LENGTH (INCHES)

? 8.93
MITIGATOR WEIGHT (GRAMS)

? 4480
INPUT MITIGATOR-MEM POSITION (INCHES)

? 30.38
CAMERA OPERATOR CODE

? 7
DISTANCE FROM NOSE TO FIRST STRIPE (INCHES)

? 4.25
PROBE STANDOFF DISTANCE (CENTIMETERS)

APPENDIX D

```
? 4.71

VACUUM AND LIGHTS BEING CHECKED
CON
GUN IS NOW READY TO FIRE!

TYPE 'FIRE' TO FIRE GUN

? FIRE
CON
 104.384       2300        16:02:39
SET TAB AT 10 THEN HIT CR.
?
          INPUT TOTAL CRUSHED MITIGATOR LENGTH (INCHES)

          ? 7.03
          INPUT MEM TIME

          ? 4846
          INPUT EVENT TIME

          ? 13736
          DO YOU WISH TO CORRECT CAMERA SPEED

          ? NO
          COMMENTS

          ?

7-INCH AIR GUN TEST RESULTS
---------------------------

SHOT # 28     02/14/74        (16:02:39)

TEST PERFORMED FOR MR. OTTEN   (639285)

PROJECTILE # 4  (FLAT NOSE)
          BIRD WEIGHT                5740 GRAMS
GUN (SEVEN INCH)
          FIRING PRESSURE             .00 PSIG
          VACUUM WAS USED
          PHOTOCELL TIME             2300 MICROSEC
          TEST PERFORMED BY MR. BALL
MITIGATOR WAS 7.875 X 7.875 MARINE PLYWOOD
          MITIGATOR WEIGHT           4480 GRAMS
          INITIAL MITIGATOR LENGTH   8.93 INCHES
          CRUSHED MITIGATOR LENGTH   7.03 INCHES
MOMENTUM EXCHANGE MASS
          MEM WEIGHT                20838 GRAMS
          MEM PHOTOCELL TIME         4846 MICROSEC
          MEM VELOCITY              103.2 FT/SEC
```

```
HIGH SPEED STREAK CAMERA
          STREAK CAMERA SPIN          104.4 RPS
          CAMERA LOCATION               .46 INCHES
          CAMERA OPERATED BY MR. MARY

COMMENTS
          A  5  INCH DIAMET'R RESTRICTION WAS EMPLOYED
             AT THE BREECH TO RESTRICT MUZZLE VELOCITY.

RESULTS
   CRUSH MEASUREMENT:
          MAX LAUNCH G               45.1  G
          STOPPING DISTANCE           3.50 INCHES
          IMPACT VELOCITY            434.8 FT/SEC
          AVERAGE ACCELERATION       10000 G
          IMPACT TIME                 1.34 MILLISEC
   PHOTOCELL MEASUREMENTS:
          EVENT PHOTOCELL TIME       13736 MICROSEC
          AVERAGE ACCELERATION       10100 G
          FINAL BIRD VELOCITY         14.4 FT/SEC
          IMPACT TIME                 1.28 MILLISEC

SHOT #  28
639285
READ FILM AT INCREMENTS OF  5219  MICRONS
# OF SCANS PER INCH  6


--28
0893
1044
3574
0046
0441
21


-----
OK TO FILE

? NO
```